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Finite population based call admission control in integrated Cellular ad-hoc relaying system

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Abstract

This paper presents an analytical model for analyzing the handoff performance of the finite population Integrated Cellular Ad hoc Relaying (iCAR) system. The analytical model is used to investigate the new call blocking and handoff dropping probabilities with and without call admission control (CAC) schemes. The finite population fractional guard channel (FPFGC) scheme is deployed as the CAC scheme in the iCAR system, which allows the reservation of a real number of channels rather than an integer number of channels. We compare the performance of the finite population iCAR system with conventional cellular systems in terms of the call blocking/dropping probability. Our results show that handoff performance benefits of the iCAR system over conventional cellular systems. The proposed policy is shown to be much lower call dropping probability than cellular networks, when the population size is large. Also, the call blocking/dropping probability in a congested cell and the overall system can be reduced with a limited number of ad hoc relaying stations.

Keywords: iCAR; call admission control; Ad hoc; relay; handoff.

1. Introduction

The Integrated Cellular and Ad hoc Relaying (iCAR) system is a new wireless architecture based on the integration of cellular and modern Ad-hoc relaying technologies to address the congestion problems due to limited wireless bandwidth and dynamically varying traffic load. It is possible to divert traffic from one cell to another cell using the Ad hoc Relaying Stations (ARSs) along with the signaling and routing protocols presented in Wu et al. [1]. The performance of iCAR system has been studied in Wu et al. [2] and Wu and Qiao [3]. iCAR system can effectively employs ARS's within the cellular network to balance traffic load among cells. More importantly, it overcome the barriers enforced by the cell boundaries and share channels between cells, which successively leads to significantly lower call blocking probability than a corresponding cellular system can achieve.

Due to increasing demand for mobile multimedia services, wireless data traffic is expected to aggravate the demand for bandwidth. But the existing call admission policy and infrastructure facing a major challenge in meeting QoS by offering high bandwidth channels. Ramjee et al. [4] studied fractional guard channel scheme to balance the load by accepting new calls with some probability along with handoff calls. Traffic load is balanced in a cell using ARS has been given in Yanmaz and Tonguz [5]. Using FGC model call dropping and blocking probability is studied in Zhaoji et al. [6].

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In urban environments with high population density, the need to increase the network capacity to avoid network congestion leads to reuse frequencies as much as possible by means of small cells forming clusters given in Boukerche [7]. When cell size is small users moving one place to another suffer from more number of handoffs. To balance the traffic load calls may consider relay to higher tiers of cells from the congested cell instead of dropping. When the cell size is small, the implicit infinite population assumption becomes unrealistic. Thus, an accurate description of the small cell case requires the development of a finite population model.

In this paper, we investigate the performance of the FGC based CAC scheme in finite population iCAR system. The rest of the paper is organized as follows. Section 2 presents system description. Section 3 presents the analytical model. The numerical results to show the effectiveness of the proposed model are presented in Section 4. Section 5 concludes the paper.

2. System description

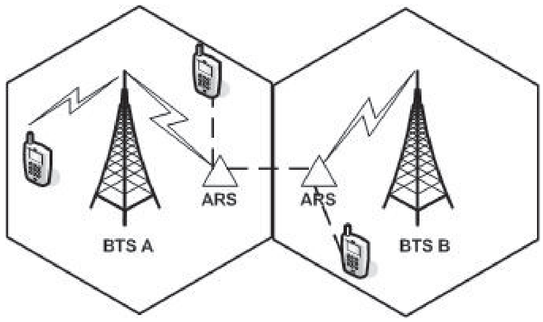

Fig. 1. Relaying system example

An Integrated Cellular and Ad hoc Relay (iCAR) system is a dynamic load balancing scheme, where an overlay ad hoc network is employed to balance traffic loads efficiently by sharing channels between congested and non-congested cells in the cellular network. Here a number of ARS are placed throughout the geographical coverage area, so that the signals between the mobile hosts (MH's) and base transceiver stations (BTS's) can be relayed. An ARS is a wireless communication device having limited mobility under control of a mobile switching centre. An example of relaying is depicted in Fig. 1, where MH in cell A (which is congested) communicates with the BTS in cell B (which is non-congested) through two ARS's. Each ARS and MH is assumed to have two air interfaces, one for communicating with the BTS's and the other for communicating with the MH's and other ARS. Increase in the network capacity leads to reuse frequencies as much as possible by means of small cells which prove high-bandwidth services. An accurate description of the small cell case requires the development of a finite population model. The cellular system under study consists of a set of hexagonal radio cells with finite population which is rated in different tiers. All cells in same tier are considered to be homogeneous and experience the same traffic patterns. To place a number of ARS at strategic locations, an iCAR system can be used to relay signals between MHs and base stations. This helps to balance congestion, and makes it possible to maintain calls involving MHs that are moving into a congested cell. This allows us to consider one cell from tier A and one cell from tier B for our performance study.

We assume that each BTS has C traffic channels and each ARS has R traffic channels. ARS are evenly distributed at shared border of two cells and their numbers are denoted by n. The ARS coverage area is normalized with respect to the base station coverage area and is denoted by p for $0 < p \leq 1$. The probability that a cell in tier B is busy at an arbitrary instant is denoted by b. Population of the congested cell A and non congested cell B is assumed to be finite and denoted by K and V, respectively. We assume that the call arrival follows Poisson process with mean arrival rate λ and duration of call is assumed to be exponentially distributed with mean $1/\mu$. The residency time of a call in a cell and the coverage of ARS is also exponentially distributed with mean 1/h and 1/r, respectively. The new call acceptance probability is α_i for $0 \leq i \leq C+nR-1$ ($0 \leq \alpha_i < 1$) and $\alpha_{C+nR}=0$. We assumed a cluster of 7 cells and each cell has C channels to serve the traffic. The traffic intensities in tier A and tier B cells are T_A and T_B Erlangs, respectively. For the given traffic intensity T_A in tier A cell, we obtain the blocking probability in tier B cell, according to the Engset formula as

$$b = B_B(C, T_B) = \binom{V}{C}(T_B)^C / \sum_{j=0}^{C} \binom{V}{C}(T_B)^j.$$

3. Finite population ICAR system with FGC scheme

In this section, we present an analytical model to evaluate the traffic performance of a finite population iCAR cellular architecture using FGC scheme. We consider an iCAR system with primary relaying and analyze the blocking and dropping probability of a congested cell by relaying traffic to a non congested cell of next tier via ARS in coverage. The state transition diagram for primary relaying is shown in Fig. 2.

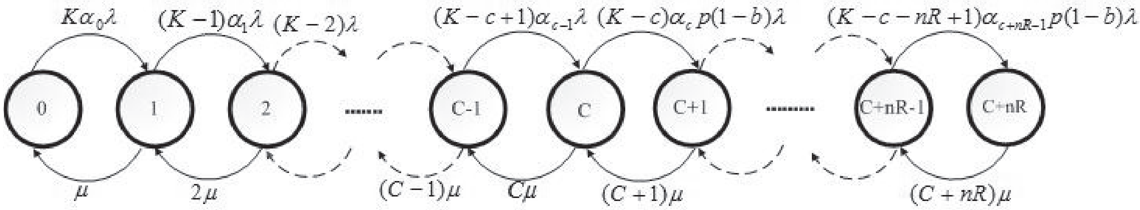

Fig. 2. State transition diagram

Let P_j be the steady state probability that there are j channels busy. In state j, the total arrival rate request to the BTS is given by $(K-i)\alpha_i\lambda$ ($0 \le i \le C-1$). When, $0 \le j < 1$ the state changes from j to j+1 if a call arrives in cell A and when a call completes the state j is reduced to j-1. When all the C channels are busy, a new call request is relayed to the tier B cell with probability of available channel (1-b). The arrival request to the ARS for relaying is $(K-i)p(1-b)\alpha_i\lambda$ ($C \le i \le C+nR-1$). The steady state probability P_j is given as follows.

$$P_j = \begin{cases} \binom{K}{j}\prod_{i=0}^{j-1}\frac{\alpha_i\lambda}{\mu}P_0 & : \quad 0 < j \le C, \\ \binom{K}{j}[p(1-b)]^{j-C}\prod_{i=0}^{j-1}\frac{\alpha_i\lambda}{\mu}P_0 & : \quad C+1 \le j \le C+nR, \end{cases}$$

and using normalization condition $\sum_{j=0}^{C+nR} P_j = 1$, we get P_0 as

$$P_0 = [1 + \sum_{j=1}^{c}\binom{K}{j}\prod_{i=0}^{j-1}\frac{\alpha^i\lambda}{\mu} + \sum_{j=C+1}^{C+nR}\binom{K}{j}[p(1-b)]^{j-C}\prod_{i=0}^{j-1}\frac{\alpha_i\lambda}{\mu}]^{-1}.$$

Using the steady state probabilities, we can obtain the handoff call dropping probability denoted by B_h as:

$$B_h = P_{C+nR} + \sum_{i=1}^{nR-1} P_{C+i}\, q_i,$$

where $q_i = 1 - \left(\frac{\mu}{\mu+h}\right)^i, 1 \le i \le nR.$
We can also obtain the new call blocking probability B_n as follows

$$B_n = \sum_{i=1}^{C+nR-1} P_i\,(1-\alpha_i) + P_{C+nR}.$$

In order to maintain the QoS the handoff call dropping probability is minimized by setting the acceptance probability as α_j=1 for $1 \leq j < C$ and $\alpha_j = \alpha$ for $C \leq j < C+nR$. We denote an overall blocking probability B_0 (or cost function) to evaluate the relative penalty from B_h and B_n, as follows

$$B_o = \gamma B_n + (1-\gamma) B_h,$$

where γ ($0 \leq \gamma \leq 1$) is a weighing factor. The value of γ depends on the emphasis laid on the quality of service requirements for B_h and B_n. Usually, interruption of handoff calls upset customers much more than blocking of new calls. In other words, B_h is more significant than B_n, hence the value of γ should be confined to be less than 0.5.

Remark 1. When the acceptance probability of new call α, for all i, then the model reduces to the finite population iCAR system without FGC scheme.

4. Numerical results and discussions

In this section, we present numerical results of performance of the FGC based CAC scheme in finite population iCAR system. We consider a cell A with traffic intensity T_A and six neighboring cells with the same traffic intensity $T_B = 0.8 \times T_A$. The parameters of the figures are taken as C=25, R=6, λ=20, μ=1 and p=0.23.

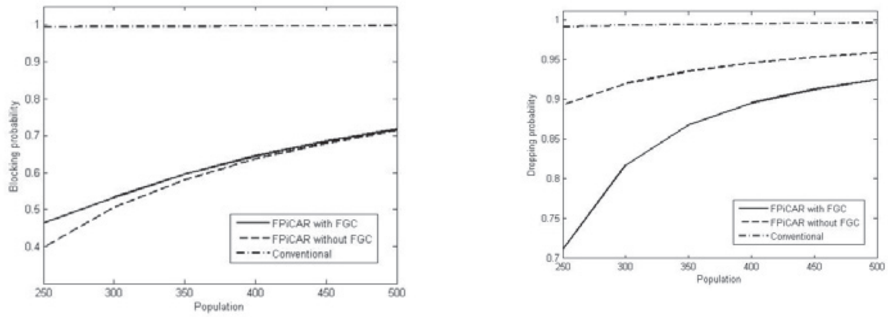

Fig. 3. Impact of population on blocking (a) and dropping (b) probability for various CAC schemes.

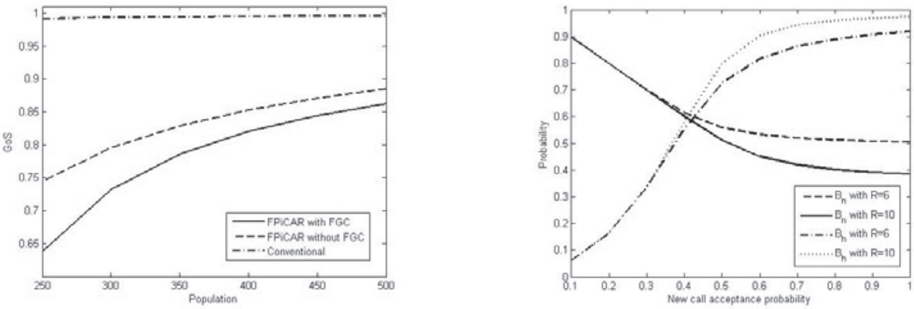

Fig. 4.(a) Impact of population on GoS for various CAC schemes; (b) Effect of α_i on blocking probability

Fig. 3(a) shows handoff call dropping probability for a wide range of population size. With the finite population FGC scheme, dropping probability increases constantly independent of the population size. Without CAC scheme, it grows speedily with the population size. It indicates that the finite population FGC scheme satisfies the target handoff call dropping probability, but the case without any CAC mechanism cannot satisfy the dropping probability when the population size is large. Fig. 3(b) depicts the call blocking probability under various population size. We observe that call blocking probability increases with population size for all the cases. Note that the case without any CAC mechanism has lower blocking probability than finite population FGC scheme, which is attained at the expense of much higher call dropping probability.

We illustrate the GoS which is the integrated evaluation for CAC schemes, in Fig 4(a). From this figure, it can be clearly seen that finite population FGC scheme outperform the case that without any CAC mechanism for iCAR system. Fig. 4(b) shows blocking and dropping probabilities versus new call acceptance probability for various R. For fixed R, as α_i increases blocking probability decreases. We observe that for fixed α_i, as R increases blocking probability decreases but dropping probability increases.

5. Conclusion

In this paper, we have presented an analytical model for the handoff performance of the finite population Integrated Cellular Ad hoc Relaying (iCAR) system. The analytical model is applied to investigate the new call blocking and handoff dropping probabilities with and without call admission control (CAC) schemes. We studied the impact of the number of ARS channels on the performance of the finite population iCAR system. Results show that acceptable levels of handoff dropping probabilities can be achieved for a small number of ARS channels if the ARS coverage is adequate.

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